1 INTRODUCTION

1.1 Mariana Archipelago

The territory of Guam and the Commonwealth of the Northern Mariana Islands (CNMI) are the westernmost territories of the United States and are part of the Mariana Archipelago (Fig. 1.1a), a chain of islands, reefs, and offshore banks located ~ 2500 km east of the Philippines and ~ 6000 km west of Hawai`i. The Mariana Archipelago is 890 km long and encompasses 15 islands and numerous offshore banks. The territory of Guam includes the island of Guam and adjacent offshore banks and reefs. All other islands and offshore banks are under the jurisdiction of the CNMI.

The Mariana Archipelago can be divided into 2 geologic groups. The old, southern islands consist of Guam, Rota, Aguijan, Tinian, Saipan, and Farallon de Medinilla, while the young, volcanic, northern islands include Anatahan, Sarigan, Guguan, Alamagan, Pagan, Agrihan, Asuncion, Maug, and Farallon de Pajaros (also called Uracas). Numerous offshore banks and submarine volcanoes are included within the U.S. exclusive economic zone (EEZ) around this archipelago. The 3 northernmost islands, the Mariana Trench, and several volcanic features between the Mariana Arc and the Mariana Trough (Fig. 1.1a) were designated as the Marianas Trench Marine National Monument by presidential proclamation in January 2009.

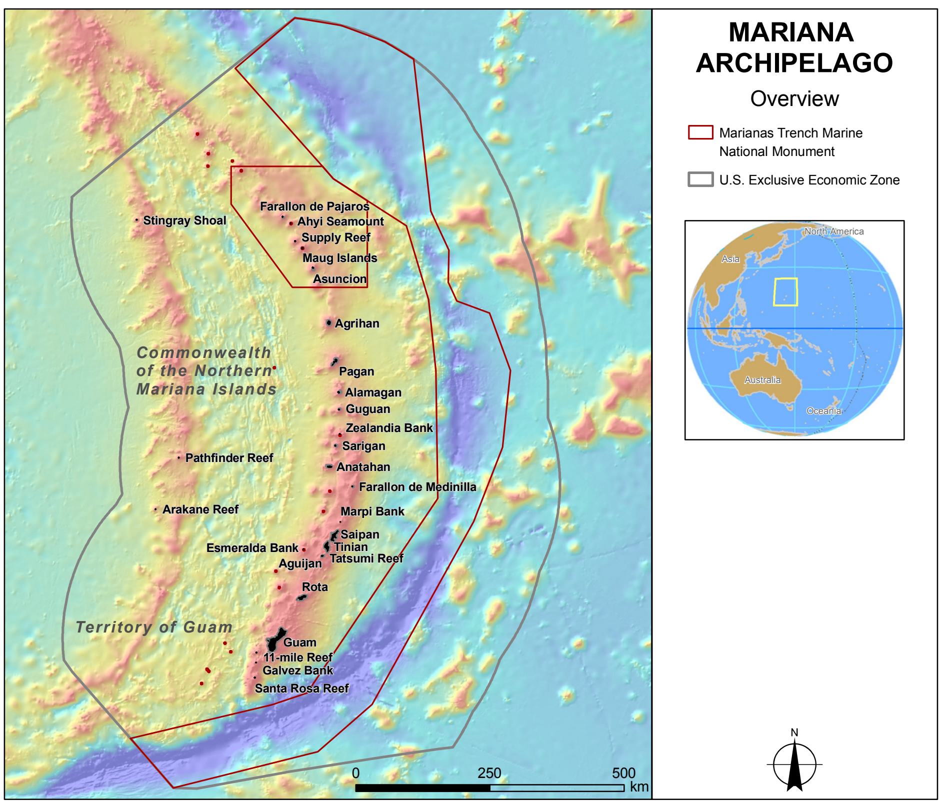


Figure 1.1a. The Mariana Archipelago includes the territory of Guam and the Commonwealth of the Northern Mariana Islands. The Marianas Trench Marine National Monument, shown above with a red outline, was created in January 2009. The grey outline indicates the boundaries of the U.S. EEZ around this archipelago.

1.1.1 History and Demographics

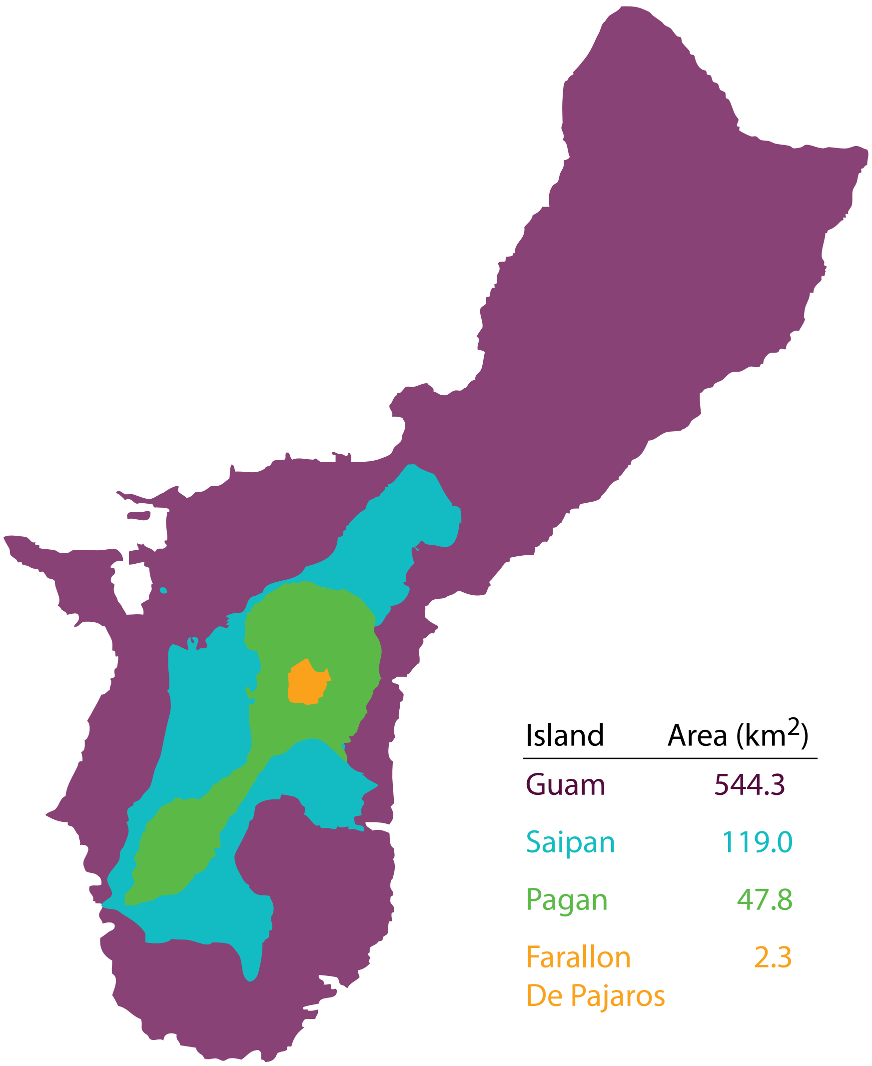
The known human history of the Mariana Archipelago, or Mariana Islands, began about 3500 years ago when Asians, who were the ancestors of the Chamorro people, arrived in these islands (Rogers 1995). Contact with the Western world began in 1521 when Magellan landed on Guam. The islands of the Mariana Archipelago were claimed by Spain in 1565. A century later, Spanish missionaries arrived and named these islands after Mariana of Austria, the widow of King Phillip IV of Spain (Rogers 1995). Disease and conflicts with Spain decimated the Chamorro population, which decreased from a level estimated between 24,000 and 100,000 in 1668 to only 3539 in 1710 (Rogers 1995; Underwood 1973). At the turn of the 18th century, Spain moved all of the remaining Chamorro people to Guam and Rota, and Spanish, Filipino, and Carolinian immigrants were brought in to resettle the Mariana Islands (Rogers 1995). Subsequent Chamorro resettlements occurred in the late 1800s (Alkire 1984). The Mariana Islands remained under control by Spain until the end of the Spanish American War in 1898, when Guam was placed under the control of the United States. Subsequently, the United States established major military bases on Guam (Rogers 1995).

Germany bought all the other islands of the Mariana Archipelago from Spain in 1899 with the intent of establishing copra plantations. During this period, Germany also let contracts for collection of exotic bird feathers for the European and Japanese hat trade (Spennemann 1999a). After World War I, the League of Nations stripped Germany of all its overseas possessions and awarded Japan administrative authority over the Mariana Islands, except for U.S.-controlled Guam. Japan established sugarcane plantations and fishing operations with an influx of 40,000 immigrants mostly from Japan, the Philippines, and the Caroline Islands (U.S. Department of the Interior [DOI] 2009a). In 1941, Japan captured Guam a few days after the Dec. 7 attack on Pearl Harbor and held the rest of the Mariana Archipelago with troops or settlers on the islands of Rota, Tinian, Agrihan, Saipan, Anatahan, and Pagan (more than 30,000 Japanese resided on Saipan alone in 1945). After intense fighting in the summer of 1944, the United States recaptured Saipan in July and Tinian and Guam in August, and the remainder of the islands were turned over to the United States after the war ended. Most of the Japanese survivors who did not believe the war was over were evacuated from Anatahan in 1951, and one last survivor was found on Guam in 1972 (Trefalt 2003). In 1947, the United Nations created the Trust Territory of the Pacific Islands (TTPI), which included all the Mariana Islands except for Guam and was administered by the United States. Guam became a U.S. territory in 1950 (Rogers 1995).

The current political structures of the CNMI and Guam are different because of the nature of their relationships with the United States (commonwealth versus territory) and the time frame in which their relationships were established. For the first 4 decades of U.S. control, from 1898 to World War II (WWII), Guam was administered by the U.S. Navy with a naval officer serving as governor. After occupation by Japan during WWII and recapture by the United States, Guam became an organized, unincorporated territory when the U.S. Congress passed the *Organic Act of Guam* in 1950. The *Organic Act* gave the people of Guam U.S. citizenship, for which they had petitioned since 1902 (Rogers 1995). Administration of Guam was transferred from the U.S. Department of Defense to the DOI, Office of Insular Affairs, in 1950 (DOI 2009a). As an unincorporated territory, Guam belongs to but is not a part of the United States, and no guarantee of eventual statehood is implied. The governor of Guam was appointed by the United States until 1968 when the *Organic Act* was amended, and the first gubernatorial election was held in 1970. Federal legislation awarded Guam a delegate in the U.S. House of Representatives in 1972. This delegate can participate and vote in House committees. The *Organic Act* also transformed the existing Guam Congress into a lawmaking body, but Guam's legislation is still subject to the will of the U.S. Congress. (Howe et al. 1994) The governor and lieutenant governor of Guam are chosen jointly with a single vote applicable to both offices for 4-year terms (Governor… 2006).

The islands of the CNMI first became officially affiliated with the United States after the U.S. military won battles on them against Japan near the end of WWII and in 1947 became part of the TTPI. The United States became the administering authority of the TTPI under the terms of a trusteeship agreement. In 1975, the people of the Northern Mariana Islands voted to become the Commonwealth of the Northern Mariana Islands, and, in 1976, the U.S. Congress approved a mutually negotiated covenant to establish the CNMI in political union with and under the sovereignty of the United States. This agreement ceded control of foreign affairs to the United States but allowed the CNMI to administer its own immigration and minimum wage laws. The CNMI government adopted its own constitution in 1977, and the constitutional government took office in January 1978. The covenant was fully implemented on November 3, 1986, by presidential proclamation, which named the Northern Mariana Islands as a U.S. commonwealth and conferred U.S. citizenship on legally qualified CNMI residents. In 1990, the United Nations terminated the TTPI. The CNMI is self-governing with locally elected governor, lieutenant governor, and legislature. Like their counterparts on Guam, CNMI citizens do not vote in elections for U.S. president and vice president but may vote in Democratic and Republican presidential primary elections. The CNMI had only an appointed "resident representative" to the U.S. House until 2008, when President George W. Bush signed a bill providing for the election of a representative. The first elected representative, who has the same voting rights as other territorial delegates, went to the U.S. Congress in 2009. In 2005, the U.S. Congress passed a bill that began to "normalize" minimum wages in the CNMI to the same rate required by law in the United States, and in 2008 other legislation turned over control of CNMI immigration laws to the United States. (DOI 2009b)

The islands of the CNMI and Guam differ in size, isolation, and human population. Guam, the largest island with an area of 544 km², had an estimated population of 159,358 persons in 2010 (U.S. Bureau of the Census 2011b), and significant growth is expected as the U.S. Department of Defense plans to move between 4700 and 8000 Marines, as well as other personnel, to Guam (Parrish 2012; Hart 2012). An enviornmental impact statement completed by the U.S. Navy in 2010 estimated that the move of additional active-duty and civilian military personnel and dependents to Guam will increase the population on this island by 24,713 persons within the next decade (U.S. Department of the Navy 2010). Farallon de Medinilla and areas of Tinian and Saipan are also used for military training activities, and these and other islands of the CNMI are under consideration for expanded military use. Saipan is the largest island in the CNMI with an area of 119 km² (Fig. 1.1.1a), roughly similar to the combined area of 160 km² for the 9 northernmost islands of the CNMI.



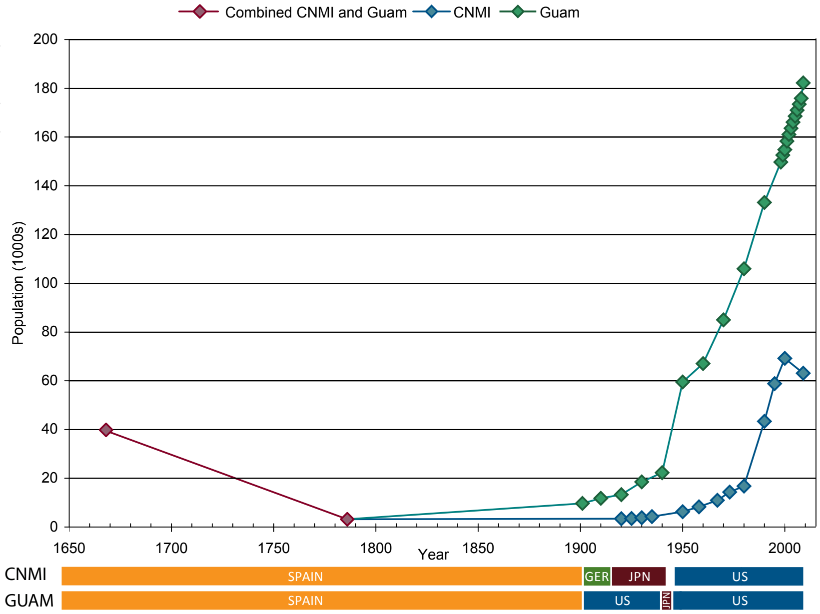
Island	Area (km^2)
Guam	544.3
Saipan	119.0
Pagan	47.8
Farallon De Pajaros	2.3

Figure 1.1.1a. The islands of the Mariana Archipelago vary widely in size. Saipan, the largest island in the CNMI, for example, is 22% of the size of the island of Guam. Among the northern volcanic islands, Pagan is the largest and Farallon de Pajaros and Maug are the smallest islands.

The combined population of Guam and the CNMI in 2010 was estimated at 213,241 (Fig. 1.1.1b; U.S. Bureau of the Census 2011a, 2011b), with population centers largely focused around 4 of the 6 old, southern islands: Guam, Rota, Tinian, and Saipan. Aguijan, located near the southern point of Tinian, has a steep, inaccessible shoreline and has remained largely uninhabited following WWII. Farallon de Medinilla is a tiny islet north of Saipan that has also remained unpopulated and primarily has been used for military operations. The U.S. Congress authorized continued military use of this islet in the *Bob Stump National Defense Authorization Act for Fiscal Year 2003* (Migratory… 2007), and live fire exercises were ongoing in 2012 (Pacific News Center 2012). All of the young, northern islands, except Farallon de Pajaros and, perhaps, Maug and Guguan, have supported human populations at some point, starting with an unknown number of native Chamorro settlements ~ 3500 years ago.

During the period of contol by Germany in 1899–1914, human populations on the Northern Mariana Islands were relatively small (Spennemann 1999a). According to U.S. Census reports, populations on these islands, excluding Saipan, Tinian, and Rota, fluctuated between 100 and 300 occupants under control by Japan and the United States from 1920 to 1980 (U.S. Bureau of the Census 1983; CNMI Department of Commerce 2002a; Office of the High Commissioner 1959). After a major volcanic eruption at Pagan in 1981, the CNMI government, which was then only recently established, evacuated all residents from the northern islands, which have remained largely uninhabited aside from small and sporadic populations at Agrihan, Pagan, Alamagan, and Anatahan.

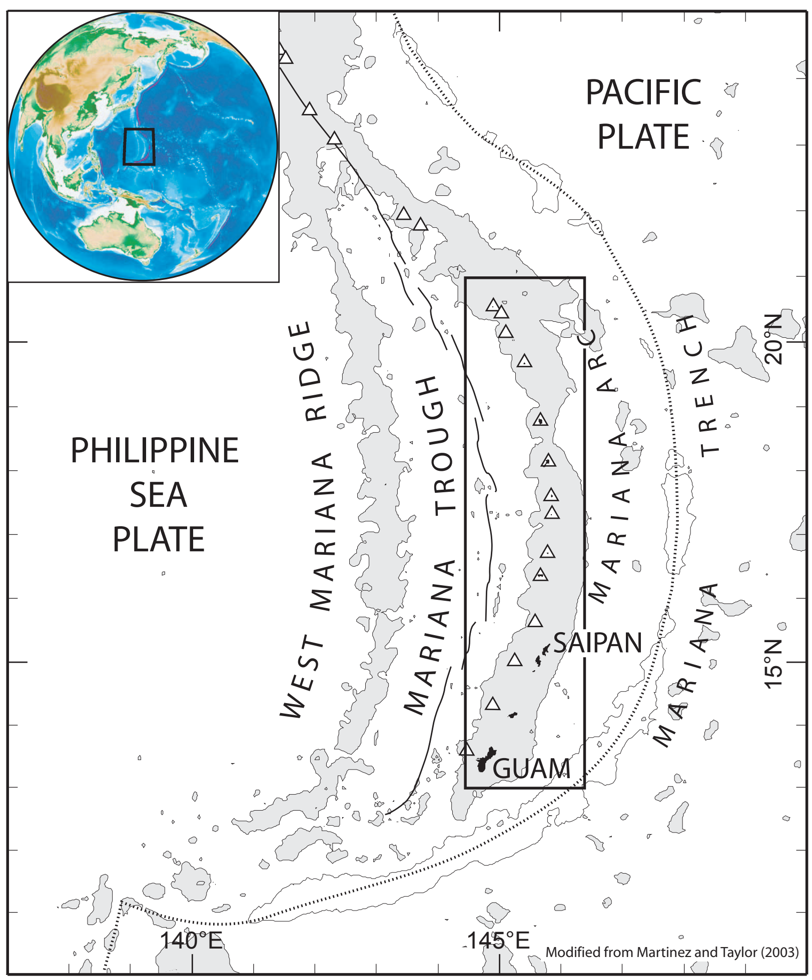
Figure 1.1.1b. Population growth of the Mariana Archipelago 1668–2009 (U.S. Bureau of the Census 1982, 1983, 1992, 2002, 2003, 2011a, 2011b; CNMI Department of Commerce 2002a; U.S. Department of Defense; Office of the High Commissioner 1959; Underwood 1973).



1.1.2 Geologic and Geographic Setting

The 6 southern islands of the Mariana Archipelago share a similar geologic structure, were formed in the late Eocene to early Miocene epochs (15–20 million years ago; Hawkins 2003), and are part of the frontal arc of the Mariana arc-trench system (Fig. 1.1.2a). Although these southern islands are volcanic in origin, they are all largely covered by uplifted limestone from ancient coral reefs. These episodically uplifted limestone terraces create planar "layer-cake" topographies

Figure 1.1.2a. Geologic setting of the Mariana region, modified from Martinez and Taylor (2003).



(Fig. 1.1.2b) with numerous above-ground and underwater caves. In comparison with the other southern islands, Guam is unique in that uplifted limestone covers its northern half, while the southern half is primarily covered by heavily eroded Eocene volcanics with no limestone cover (Fig. 1.1.2c; Riegl et al. 2008).

Figure 1.1.2b. Flat-topped Forbidden Island is an uplifted, fossil coral reef platform on the island of Saipan. *NOAA photo by Molly Timmers*

Figure 1.1.2c. Watersheds in southwestern Guam are steep-sided, with Eocene volcanic rocks and red, easily eroded laterite soils. *Photo courtesy of the Water and Environmental Research Institute of the Western Pacific and Island Research & Education Initiative*

The northernmost islands of the Mariana Archipelago are part of the Mariana Arc, where the Pacific Plate is subducted beneath the Philippine Plate at the Mariana Trench, which lies ~ 130–210 km east of this island chain. These northern islands, spanning from Anatahan to Farallon de Pajaros, are all stratovolcanoes characterized by steeply sloping surfaces and periodic, explosive eruptions. These islands are predominantly composed of hardened lava, tephra, and volcanic ash, which result from the re-melting and subsequent eruption of subducted material.

The West Mariana Ridge is a remnant volcanic island arc that forms a series of seamounts 145–170 km west of and parallel to the main island chain. The West Mariana Ridge is of intermediate age: younger than the southern part of the Mariana

Arc and older than the northern part of the Mariana Arc. Some of these seamounts rise to within 9 m of the ocean surface and were probably, at some point in time, above sea level. The absence of terrestrially derived sediments, recent volcanic ash, and infrequent direct anthropogenic impact at the West Mariana Ridge contribute to the near-optimal conditions for coral growth. Accordingly, some of the shallow structures feature well-developed reef ecosystems with lush gardens of hard corals (Fig. 1.1.2d).

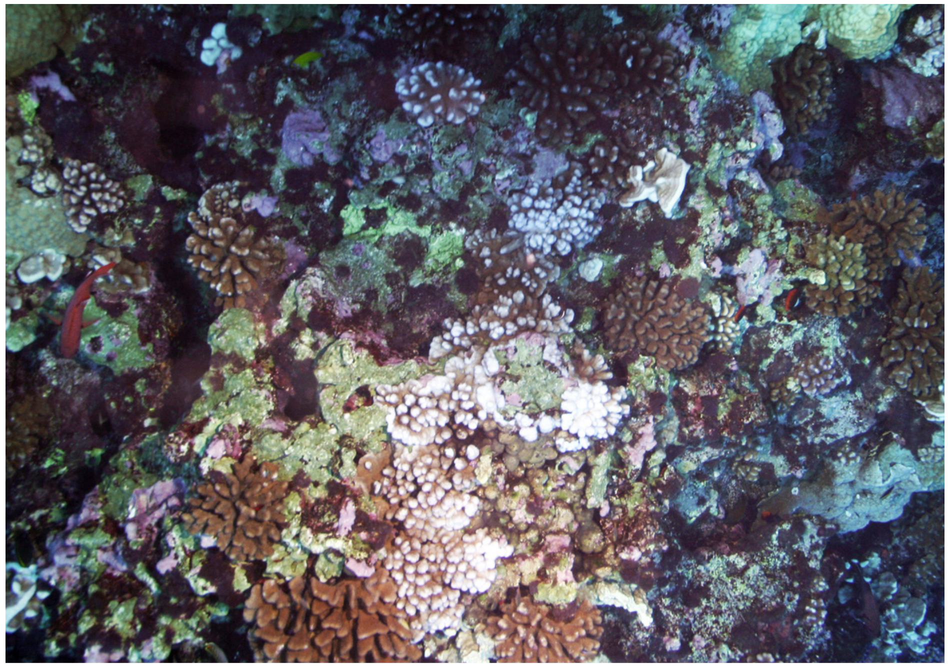


Figure 1.1.2d. Luxuriant coral growth at Stingray Shoals in the West Mariana Ridge, which is ~ 275 km west of Farallon de Pajaros. *NOAA photo*

Offshore banks and their associated habitats can be formed through 2 major types of events: (1) rapid tectonic or volcanic events, such as landslides, uplifts, or eruptions and (2) long-term changes in sea level, resulting in coral growth or erosion. For at least the past 800,000 years, global sea level has fluctuated ~ 120 m over every period of ~ 100,000 years in response to glacial-interglacial cycles. In the current interglacial period, sea level is near the peak of this 120-m oscillation (Ruddiman et al. 1989). When sea level is static for a prolonged period, the sea tends to erode terraces into land areas or form offshore platforms.

Because of their hybrid geological history, islands in the Mariana Archipelago, their immediately surrounding banks, and the banks that lie farther offshore represent a composite of these influences. In the young, volcanically active northern islands, such as Pagan, Alamagan, and Maug, some terraces and offshore formations are clearly extensions of recent onshore lava flows into offshore areas, and some of the terraces were formed during previous sea-level stands. In the old, southern islands, previous sea-level stands have formed carbonate terraces on top of volcanic structures from the Eocene to Miocene epochs, and these terraces subsequently have been exposed to sea-level change and, because of tectonic activity, have been uplifted or downthrown.

1.2 Coral Reef Management

1.2.1 National Coral Reef Management

In 1998, President Bill Clinton signed Executive Order no. 13,089 to "preserve and protect the biodiversity, health, heritage, and social and economic value of U.S. coral reef ecosystems and the marine environment" (Coral… 1999). This executive order created the U.S. Coral Reef Task Force (CRTF), with the secretaries of interior and commerce acting as co-chairs and federal agencies acting as participants. Working with state, territorial, commonwealth, and local governments, as well as nongovernmental organizations and commercial interests, this task force has 4 primary tasks:

1. Coordinate a comprehensive program to map and monitor U.S. coral reefs
2. Develop and implement research aimed at identifying the major causes and consequences of degradation to coral reef ecosystems
3. Develop, recommend, and seek or secure implementation of measures necessary to reduce and mitigate coral reef

ecosystem degradation and to restore damaged coral reefs

4. Assess the role of the United States in international trade and protection of coral reef species, and implement appropriate strategies and actions to promote conservation and sustainable use of coral reef resources worldwide

Executive Order no. 13,089 set the stage for national coral reef conservation efforts—emphasizing the need to undertake a comprehensive, rather than location-specific, program of ecosystem research, mapping, and monitoring of all U.S. coral reefs. In 2000, the CRTF developed the *National Action Plan to Conserve Coral Reefs* (National Action Plan) as the first U.S. blueprint to focus on the loss and degradation of U.S. and international coral reef ecosystems. Coral reef conservation was framed in 2 broad themes (U.S. Coral Reef Task Force 2000):

1. Understanding coral reef ecosystems
2. Reducing the adverse impacts of human activities

The National Action Plan stated, "Ultimately, our success—or failure—in conserving these highly complex and extremely fragile ecosystems will depend on a parallel approach of proactive, precautionary management measures coupled with a much more sophisticated level of understanding about their fundamental ecology and response to environmental stressors" (U.S. Coral Reef Task Force 2000). For this first theme, 4 goals were outlined:

1. Develop comprehensive maps of all U.S. reefs
2. Develop a nationally coordinated coral reef inventory, assessment, and monitoring program
3. Support strategic research focused on the determinants of coral reef health and recovery, including basic ecological processes, bleaching and disease, and best management practices for coral reefs and closely linked marine and terrestrial habitats
4. Conduct socioeconomic studies of the human dimension of successful coral reef conservation

As with Executive Order no. 13,089, the National Action Plan emphasized a nationally coordinated, comprehensive investigation of coral reef ecosystems from a mapping, research, and monitoring perspective. In the same year, the *Coral Reef Conservation Act of 2000* (CRCA; Coral… 2000), which served as the congressional response to Executive Order no. 13,089, laid out a national framework to address coal reef conservation issues. This legislation required the development of a national coral reef action strategy with goals and objectives that would include mapping, information management, research, and monitoring. The CRCA also created the national Coral Reef Conservation Program (CRCP) under the direction of the Secretary of Commerce. The CRCA requires NOAA to conduct collaborative research, mitigation, and outreach activities that directly contribute to the conservation of coral reef ecosystems. In response, NOAA performs a range of authorized activities, some of which are listed below:

1. Providing mapping, monitoring, assessment, restoration, and scientific research that benefits the understanding, sustainable use, and long-term conservation of coral reef ecosystems
2. Enhancing public awareness, education, understanding, and appreciation of coral reef ecosystems
3. Collaborating with local, regional, or international programs and partners for the cooperative conservation and management of coral reef ecosystems

NOAA, in cooperation with the CRTF, produced the *National Coral Reef Action Strategy* (National Action Strategy) in 2002 to fulfill the requirements of the CRCA and to help track the implementation of the National Action Plan. Two of the actions outlined in the National Action Strategy are listed below:

1. *Map all U.S. coral reef ecosystems* to address the threats of overfishing, habitat destruction, coastal development, and coastal pollution
2. *Assess and monitor coral reef health* to address the threats of global warming and climate change, diseases, overfishing, destructive fishing practices, habitat destruction, invasive species, coastal development, coastal pollution, sedimentation and runoff, and overuse related to tourism

As required by the CRCA, the CRCP has produced 3 "state of the reefs" reports since 2002. *The State of Coral Reef Ecosystems of the United States and the Pacific Freely Associated States: 2002* (Turgeon et al. 2002), *The State of Coral Reef Ecosystems of the United States and the Pacific Freely Associated States: 2005* (Waddell 2005), and T*he State of the Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2008* (Waddell and Clarke 2008) are designed to provide overall assessments of coral reef ecosystems in U.S. jurisdictions at the time and are organized based on the primary threats, topics, and goals outlined in the National Action Strategy. The Guam and CNMI chapters in this 2008 report (Burdick et al. 2008; Starmer et al 2008) provide an overview of monitoring activities, a summary of results to date, current management activities, and overall conclusions and recommendations.

In September 2007, an external review of the CRCP was conducted to evaluate the success of this program in meeting the purposes of the CRCA and the National Action Strategy during the period of 2002–2006 and to provide recommendations for improving this program. As a result of this external review, CRCP developed a *Roadmap for the Future* report to set CRCP's direction for the period of 2010–2015 (CRCP 2008).

The primary objective of the CRCP is to address strategic coral reef management needs in a targeted, cost-effective, and efficient manner. To make the most of limited resources and to have the largest impact in reversing the general decline in coral reef health that has occurred over the past several decades, the CRCP is now narrowing the focus of its national program and shifting allocation of CRCP resources to take on-the-ground and in-the-water action. The CRCP is focusing efforts on understanding and addressing the following 3 priority threats:

- Impacts of fishing
- Impacts of land-based sources of pollution
- Impacts of climate change

The CRCP made the strategic decision to invest part of its annual operating budget in perpetuity to support long-term, integrated, multidisciplinary monitoring on a national scale and in 2010 put together a working group to develop a National Coral Reef Monitoring Plan for providing a consistent flow of information to assess and report the status and trends of environmental conditions, living reef resources, and the people and processes that interact with coral reef ecosystems. This CRCP-funded national monitoring program will provide a consistent and comprehensive analytical backdrop for other CRCP and partner activities. For the Pacific Islands Region, this plan means that a modified version of the CRED-led Pacific Reef Assessment and Monitoring Program (Pacific RAMP) will be executed on a national basis moving forward. Development of this national plan is ongoing in 2012 and implementation will occur over several monitoring cycles, but an outcome already initiated is a shift in the frequency of Pacific RAMP cruises with monitoring activities conducted on a triennial basis rather than a biennial basis.

1.2.2 Coral Reef Management in Guam

One of the first major steps in local coral reef management on Guam occurred in 1997 when more than 10% of the Guam coastline was set aside in 5 marine protected areas (MPAs) through Guam Public Law 24-21: Piti Bomb Holes Marine Preserve, Sasa Bay Marine Preserve, Tumon Bay Marine Preserve, Pati Point Marine Preserve, and Achang Reef Flat Marine Preserve. The goal of these preserves was to increase reef fish stocks. Limited take for cultural purposes was permitted in 3 of these 5 areas, full protection was first fully enforced in 2001, and regulations were strengthened with the passage of Guam Public Law 28-107 in 2006. Legislation (Guam Public Law 29-127) passed in 2008 and modifications proposed in 2009 through Bill 190-30 may open some of these no-take MPAs to fishing by indigenous people, although there is evidence of increased fish abundance in these marine preserves (Burdick et al. 2008). In addition, the U.S. Fish and Wildlife Service has established the Guam National Wildlife Refuge at Ritidian Point, and the Navy has established 2 ecological preserves at Orote and Haputo Points.

As a response to national CRCA initiatives discussed previously, between August 2002 and February 2003, the Guam Coral Reef Initiative Coordinating Committee worked to select and prioritize which main threats to local coral reefs would be the focus of local action strategy (LAS) efforts. This process significantly expanded and enhanced the network of stakeholder groups working on coral reef issues. Members of the Guam Watershed Planning Committee, a group of local, federal, and nongovernmental agencies involved primarily with watershed restoration, also became involved in LAS development, and members of the Guam Coral Reef Initiative Coordinating Committee now participate in the Watershed Planning Committee. In addition, the University of Guam Marine Laboratory and the Water and Environmental Research Institute of the Western Pacific, guided by the needs of local natural resource agencies, have shifted much of their focus toward management-driven research. The Guam Visitors Bureau and the tourism industry as a whole now are working with these natural resources agencies to market Guam's coral reefs and, in particular, Guam's marine preserves to the 1 million visitors that travel to this island each year.

During LAS development in 2002, major issues identified for the management of Guam's coral reefs included the following 4 challenges:

1. Land-based sources of pollution
2. Fisheries management
3. Lack of public awareness
4. Recreational misuse and overuse

During a CRCP workshop held in Honolulu in November 2008, land-based sources of pollution and fisheries management were again discussed as critical issues for coral reef management in Guam (CRCP 2009). The CRCP's monitoring, mapping, and assessment activities are collectively known as the Coral Reef Ecosystem Integrated Observing System (CREIOS), so this meeting was called the "Pacific CREIOS Workshop." Listed below are some of the mapping and monitoring needs that were identified by representatives from Guam management agencies:

1. Maps of Apra Harbor to assist with management efforts associated with military expansion
2. Hydrographic data for modeling of currents and water quality
3. Assistance with integrating various types of data and information

In 2006, Guam became a signatory to the Micronesian Challenge, a program initiated by the Republic of Palau that aims to effectively conserve at least 30% of nearshore marine and 20% of forest resources across Micronesia by 2020.

The Guam chapter of *State of the Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2008* (Burdick et al. 2008) reports that the health and resiliency of Guam's coral reefs varies considerably, depending upon a variety of factors, including geology, human population density, level of coastal development, level and types of uses of marine resources, oceanic circulation patterns, coral predator outbreaks, and natural events such as typhoons and earthquakes. Burdick et al. 2008 also report that northern reefs are generally healthier than those in the south, where land-based pollution and runoff are more severe, and that fishes > 25 cm in length are uncommon to rare around all of Guam. Local and federal agencies and a variety of stakeholders have combined forces to promote re-vegetation efforts, outreach campaigns, enforcement within marine preserves, and development of a comprehensive monitoring strategy, and they have formed action groups such as the Island Pride Campaign and the Guardians of the Reef program. Financial and human resources, however, are still very limited and the challenges they face are likely to become more pronounced, particularly because of the planned military expansion and potential stressors associated with increased development (Burdick et al. 2008). This 2008 report cited specific issues of concern: wildland arson and resulting runoff; continuing severe depletion of reef fish species; and global climate change and resulting coral bleaching, ocean acidification, and increases in storm strength (Burdick et al. 2008).

1.2.3 Coral Reef Management in the CNMI

One of the first major steps in ecological protection in the CNMI was taken in 1985 when the islands of Guguan, Asuncion, Farallon de Pajaros, and Maug were established as nature preserves, through an amendment to the CNMI Constitution that stipulated that the "islands of Maug, Uracas, Asuncion, Guguan, and other islands specified by law shall be maintained as uninhabited places and used only for the preservation and protection of natural resources, including but not limited to bird, wildlife, and plant species" (CNMI Constitution).

A Marine Monitoring Team (MMT) was established in 1997 to foster better understanding of the condition of coral reefs and reef resources. Members of the MMT include the Division of Environmental Quality (DEQ), Division of Fish and Wildlife (DFW), Coastal Resources Management (CRM) Office, and Northern Marianas College.

The CNMI established a Marine Sanctuary Program in 1998 under which areas around Saipan, Rota, and Tinian have been protected (Starmer et al. 2005). Saipan has 3 no-take marine reserves: Managaha Marine Conservation Area, Forbidden Island Marine Conservation Area, and Bird Island Marine Sanctuary. The Sasanhaya Fish Reserve is a no-take zone for all species on the southwest coast of Rota. The CNMI in 2006 became a signatory to the Micronesian Challenge. In 2007, CNMI Public Law 15-90 created a new no-take marine reserve on the southwest coast of Tinian from Puntan Carolinas to Puntan Diapblo.

In response to the CRTF's 2002 call for LAS, the DEQ, DFW, and CRM held a series of public meetings with the CNMI Watershed Group, the MMT, and other stakeholders. The major foci of the CNMI's LAS were identified in 2002:

1. Land-based sources of pollution
2. Fisheries management
3. Recreational use
4. Increasing awareness and involvement
5. Coral reef resources management

During the CRCP "Pacific CREIOS Workshop" held in November 2008, these LAS items were reviewed and the following mapping and monitoring needs were added or clarified (CRCP 2009):

1. Bathymetric data to fill gaps in critical shallow-water areas
2. An archipelago-wide hydrographic model to investigate larval connectivity
3. Assistance with integrating various types of data and information

In January 2009, President Bush proclaimed the 3 northernmost islands of Mariana Archipelago, Farallon de Pajaros, Maug, and Asuncion, the entire Mariana Trench, and active undersea volcanic areas of particular interest as the Marianas Trench Marine National Monument (MNM). Details of the administration of this MNM will be jointly determined by the departments of Interior and Commerce, and the CNMI government will be involved as a cooperating agency (President… 2009). The governor of the CNMI appoints government representatives to be participants in the Marianas Trench MNM management council.

The CNMI chapter of *State of the Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2008* (Starmer et al. 2008) reports that the capacity of the CNMI to manage its coral reef ecosystem resources has grown substantially over the past 7 years, thanks to U.S. Coral Reef Initiative funding. Critical goals are the development of justifiable performance indicators and programmatic self-sufficiency. LAS efforts have played a large part in the development of performance indicators, but the CNMI is just beginning to realize programmatic self-sufficiency through activities associated with fulfilling the Micronesian Challenge.

1.3 Ecosystem Approach to Management

Fishery and marine resource managers strive to make management decisions that will not only allow humans to sustainably interact with and use complex ecosystems but also ensure long-term ecosystem conservation and viability for future generations. To date, fishery management plans have traditionally focused on single stocks or, at most, commercially important groupings of stocks. Under these types of plans, fishery managers typically set biomass harvest or mortality rate goals with limited consideration of other stock characteristics or broader ecosystem concerns. In recent years, however, there has been a growing understanding that exploited marine resources must be considered as an integral component of a functioning ecosystem instead of as phenomena that operate independently of the broader biological community and environment.

Internationally, the need to move toward an ecosystem-based approach to fisheries management has been widely recognized, a shift that has been spearheaded by the Food and Agriculture Organization of the United Nations through the Code of Conduct for Responsible Fisheries and supported by numerous regional and national institutions as well as academia, nongovernmental organizations, and the public at large (Cury and Christensen 2005). In the United States, our understanding of marine ecosystems has been identified as a critical means to ground our ocean policy. The 2004 report of the U.S. Commission on Ocean Policy highlighted the importance of an ecosystem-based management approach and a vision for a future in which "management boundaries correspond with ecosystem regions, and policies consider interactions among all ecosystem components" (U.S. Committee on Ocean Policy 2004).

More recently, in its 2010 report, the Interagency Ocean Policy Task Force, created by President Barack Obama in June 2009, identified 9 priority objectives that the United States should pursue to implement a national ocean policy. The first of these priorities read, "Adopt ecosystem-based management as a foundational principle for the comprehensive management of the ocean, our coasts, and the Great Lakes" (Council on Environmental Quality 2010). Acknowledged as the second priority objective and closely linked with ecosystem-based management is the use of marine spatial planning, which is a comprehensive process through which compatible human uses are objectively and transparently allocated to appropriate ocean areas to sustain critical ecological, economic, and cultural services for future generations.

Executive Order no. 13,547, which was signed by President Obama on July 19, 2010, adopted those priority objectives and other recommendations of the Interagency Ocean Policy Task Force, created the National Ocean Council, and established the country's first *National Policy for the Stewardship of the Ocean, Our Coasts, and the Great Lakes* (Stewardship… 2010). "To achieve an America whose stewardship ensures that the ocean, our coasts, and the Great Lakes are healthy and resilient, safe and productive, and understood and treasured," this executive order stated, "it is the policy of the United States to…increase scientific understanding of ocean, coastal, and Great Lakes ecosystems as part of the global interconnected systems of air, land, ice, and water, including their relationships to humans and their activities."

In theory, an ecosystem-based approach to management might overcome the challenges of addressing issues that cross traditional jurisdictional boundaries (local, state, national, and international) and of continually adapting to new scientific information and improved management tools. The Interagency Ocean Policy Task Force in its 2010 report described ecosystem-based management as an approach that "recognizes both that humans are key components of ecosystems and also that healthy ecosystems are essential to human welfare" (Council on Environmental Quality 2010). The U.S. Committee on Ocean Policy (2004) report also acknowledged that our management approach should account for the complex interrelationships between abiotic environmental factors driving oceanic, atmospheric, and terrestrial processes and their interaction with living organisms on systematic ecological levels.

While there is general agreement on the need to transition to ecosystem-based fisheries and marine resource management, vigorous debate continues at all levels on how to implement policies to accomplish this transition. Still, there is, particularly among management agencies, agreement on the need for unbiased, credible, and up-to-date scientific information that examines the status and trends of ecosystem health and increases the understanding of mechanistic functions that determine ecosystem processes.

As an example of ongoing efforts in the Pacific Islands Region, the Western Pacific Fishery Management Council (WPFMC) established in 2001 its *Coral Reef Ecosystems Fishery Management Plan*, an ecosystem-based plan that in 2002 was approved by the National Marine Fisheries Service and in 2004 received a final ruling (Fisheries… 2004), and followed up with the development of archipelagic fishery ecosystem plans for the regions in its jurisdiction. The *Fishery Ecosystem Plan for the Mariana Archipelago*, which was published in 2009 and codified in 2010 (Western… 2010; WPFMC 2001) represents the first step in an incremental and collaborative endeavor to implement ecosystem approaches to fisheries management in the Mariana Archipelago (WPFMC 2009).

Moreover, there is similar consensus on the need to translate scientific findings into useful and timely information products for policymakers, managers, educators, and the public. Resource managers and policymakers need a foundation of reliable scientific information to make informed decisions and effectively implement ecosystem-based management principles with the objective of balancing sustainable use and long-term ecosystem conservation, including conservation of biodiversity, protected species, and habitats.

1.4 Pacific Reef Assessment and Monitoring Program

1.4.1 Background and Purpose

In response to the executive and legislative mandates and policies previously outlined in this chapter (see Section 1.2: "Coral Reef Management" and Section 1.3: "Ecosystem Approach to Management"), including Executive Order no. 13,089, the National Action Plan, and the *Coral Reef Conservation Act of 2000*, the Coral Reef Ecosystem Division (CRED) of the NOAA Pacific Islands Fisheries Science Center (PIFSC) was formed in 2001 with the support of the CRCP. The mission of CRED is to lead an integrated, interdisciplinary, ecosystem-based program of research, mapping, and long-term monitoring of coral reef ecosystems of the U.S. Pacific islands to promote conservation, management, and public awareness through innovative and collaborative science of the highest integrity.

Sustainable management and long-term conservation of coral reef ecosystems of the U.S. Pacific islands require comprehensive habitat mapping and interdisciplinary ecosystem assessment and monitoring of environmental conditions, biological communities, and human-use practices. The goal of CRED is to provide high-quality, unbiased ecosystem-based data and value-added information products to resource managers and policymakers on local, regional, national, and international levels in a timely manner.

CRED leads the Pacific RAMP as a key component of these efforts, conducting comprehensive ecosystem monitoring surveys every 3 years at ~ 50 islands, atolls, and shallow banks in the Hawaiian Archipelago (main Hawaiian Islands and Northwestern Hawaiian Islands), the Mariana Archipelago (territory of Guam and the CNMI), territory of American Samoa, and the Pacific Remote Island Areas (Wake, Johnston, Palmyra, and Kingman Atolls and Howland, Baker, and Jarvis Islands). To accomplish this monitoring, CRED uses NOAA research vessels capable of supporting multidisciplinary research teams of 20–22 scientists for extended voyages lasting 2–3 months.

Pacific RAMP cruises are conducted in collaboration with colleagues and partners from other NOAA offices; federal, state, and territorial agencies; academia; industry; and nongovernmental organizations. These partnerships are essential to the effectiveness of long-term ecosystem monitoring in this region because they bring together marine scientists and managers with local, regional, national, and international experience over a broad range of scientific and management issues. They also provide much needed logistical and operational support for CRED activities.

CRED's integrated coral reef ecosystem monitoring uses a suite of complementary methods to assess corals, algae, other invertebrates, fishes, and microbes in the context of their benthic habitats and oceanographic and water-quality environments. These methods are used consistently across the Pacific Islands Region to enable comparative ecosystem analyses across diverse biogeographic, environmental, oceanographic, and socioeconomic (human use) gradients. Ecological gradients include biodiversity, endemism, geomorphology (high or low island), island landmass, and reef classification and zonation. Environmental and oceanographic gradients include temperature (based on seasonal and interannual variability or geographic location), wave energy, tropical storm frequency and intensity, current patterns, precipitation and runoff, and water quality (nutrient availability) and carbonate chemistry. Socioeconomic gradients include population density, coastal development, fishing pressure, agricultural use, and cultural practices. Having similar interdisciplinary observations of coral reef ecosystems across these complex and diverse gradients makes it possible to significantly improve our understanding of ecosystem relationships and implicate cause-and-effect mechanisms that influence the health and resilience of coral reef ecosystems.

The integrated monitoring and assessment efforts of the Pacific RAMP are part of a diverse array of research platforms, tools, and methods that CRED uses to support the CRCP's CREIOS in the U.S. Pacific islands (see Chapter 2: "Methods and Operational Background").

1.4.2 Scope of the Pacific RAMP

The Pacific RAMP encompasses comprehensive efforts to map, assess, and monitor the coral reef ecosystems of the U.S. Pacific islands. In this process, CRED provides data and information products to resource managers and policymakers on local, regional, national, and international levels. This broad scope reflects the reality that coral reef ecosystems are influenced by local, regional, and global processes and stressors.

Although local resource managers generally implement policies that influence human uses of and impacts to local resources, ecosystems are significantly influenced by processes both within and well beyond local jurisdictional boundaries. The Pacific RAMP aims to assist local and regional resource managers by providing essential information about these biogeographic and ecological processes that influence local and regional resources. As such, the Pacific RAMP is envisioned as a key component of the national backbone to provide broad-scale baseline assessments for the Pacific Islands Region. These baseline assessments are explicitly expected to be complemented by more focused, local monitoring programs within each jurisdiction, including those jurisdictions funded by CRCP-administered coral reef monitoring grants. Pacific RAMP efforts provide the ecological and oceanographic context within which local ecosystems are embedded. These extensive spatial and temporal surveys across the Pacific Islands Region support and guide local monitoring efforts by helping to identify ecological concerns and defining the appropriate questions for more specific, local-level research and monitoring.

One of the key goals of the Pacific RAMP is to provide essential observations to describe, understand, and predict ecological and environmental conditions across broad—and inherently variable—spatial and temporal scales. Although local and regional resource managers and policymakers cannot manage or directly influence these large-scale processes, it is important to recognize that they cannot effectively manage local resources without good information, knowledge, and predictions about these large-scale processes. Certainly, ecological processes and changes occur at spatial and temporal scales that are finer than the scale observed by the Pacific RAMP. Yet many of the pervasive and chronic threats facing coral reef ecosystems are taking place on global and climatic time and space scales.

The temporal scope of the Pacific RAMP, with surveys conducted initially every 2 years and now every 3 years, is designed for observing and improving our understanding of ecosystem variability over time scales ranging from many years to decades or centuries. More specifically, this program is designed to examine the potential ecological impacts of long-term threats facing coral reefs, including threats related to climate change, fishing, coastal development, and land use:

- Mass coral bleaching and increased incidence of coral diseases in response to ocean warming
- Decreased calcification rates of corals, crustose coralline algae, and other calcifying organisms in response to ocean acidification and based on changing water chemistry (increased uptake of carbon dioxide from the atmosphere)
- Restructuring of many coastal and reef communities in response to rising sea levels, changing storm tracks and intensities, and modified ocean circulation patterns
- Changes in coral reef ecosystem communities (corals, algae, invertebrates, fish) in response to the impacts of fishing
- Effects of pollution, runoff, and sedimentation on corals reefs associated with coastal development and land-use practices

Although most of these potential threats are poorly understood today, they clearly pose significant risks to coral reef ecosystems across all scales ranging from local to regional to global. Recent analyses (Kleypas et al. 2006) suggest that the combined impacts of ocean acidification and warming could potentially dwarf those of many of the traditional local stressors (fishing, coastal development, pollution, etc.) with which marine resource managers currently struggle. As these global- and climate-scale processes become better understood, the need for the long-term, broad-scale ecosystem observations (biotic and abiotic) provided by the Pacific RAMP is becoming more evident and essential.

1.4.3 Pacific RAMP in the Mariana Archipelago

Pacific island communities are economically and culturally dependent on their marine resources. Accurate and up-to-date characterizations of the coral reef ecosystems of the Mariana Archipelago are necessary to develop and evaluate effective management strategies. The ecosystem "snapshots" acquired during Pacific RAMP surveys are used to identify both spatial and temporal (short- and long-term) changes of coral reef organisms and their environment. Thus, the ecosystem-based program that CRED has developed for reef assessment and monitoring in the Mariana Archipelago will provide local, regional, and national resource managers with reliable scientific information to more effectively implement ecosystem approaches to management in the region.

As part of its Pacific-wide monitoring effort, CRED conducted its first Mariana Archipelago Reef Assessment and Monitoring Program (MARAMP) cruise in 2003, with subsequent cruises in 2005, 2007, 2009, and 2011. The next MARAMP cruise is planned for 2014. Partners from the CNMI (the DEQ, DFW, and CRM) and from Guam (the Division of Aquatic and Wildlife Resources of the Department of Agriculture, Bureau of Statistics and Plans, Guam Environmental Protection Agency, and University of Guam) worked alongside CRED scientists to plan and conduct surveys and determine and establish monitoring sites.

The value of the MARAMP effort may not have been fully realized during its earlier stages. Based on observations to date, however, scientists and managers can begin to characterize spatial patterns of variability of the reef ecosystems around Guam and the CNMI and compare them to other regions in the Pacific. The value of Pacific RAMP and MARAMP will increase steadily as observations extend in time and the ability to detect significant ecological changes and climate fluctuations advances. Over time, ecological and environmental trends may include biodiversity shifts, population shifts, sudden species die-offs, disease outbreaks or bleaching pandemics, and introductions of bioinvasive species. With continually improved observations and understanding, our ability to develop predictive models will likewise increase and, thereby, provide managers with better tools for protecting and conserving reef resources. CRED is committed to providing superior, unbiased, and integrated ecosystem observations of the coral reefs of the Mariana Archipelago, as well as of other U.S. jurisdictions in the Pacific, well into the future.

1.4.4 Limitations and Improvements of Pacific RAMP

As with any large research effort, the Pacific RAMP has numerous logistical, operational, and scientific constraints. These limitations shape the nature of the data presented within the body of this Monitoring Report and provide a matrix for future improvement and continued program development. Program limitations are discussed here to clarify the current state of CRED's Pacific RAMP, the nature of the data, and the future of this program's research.

Since the beginning of this ecosystem assessment and monitoring program, CRED has worked with partners in each jurisdiction to develop, adapt, and implement comprehensive Pacific RAMP surveys. During this program's initial years of 2000–2003, several monitoring programs were in place across the Pacific and many monitoring workshops evaluated scientific methods and approaches. Despite this activity, however, there was and still is little consensus within the scientific community on any singular investigative approach. Moreover, as CRED and the Pacific RAMP were being established, few, if any, examples existed of coral reef monitoring programs with a similar geographical scale or interdisciplinary, ecosystem-based scope. As a newly established program, CRED and affiliated partners needed to accomplish the following objectives:

- Determine, develop, test, and adapt sampling methods and protocols
- Create protocols, algorithms, and tools for data processing, quality control, and analysis
- Devise and implement a data management, integration, and dissemination infrastructure

A significant majority of the ~ 50 islands, atolls, and banks surveyed by the Pacific RAMP had virtually no prior ecological surveys, bathymetric or habitat maps, or in situ oceanographic observations. Little or no information was available about what to expect in terms of habitats, biogeographic structure, oceanographic conditions, or species compositions, distributions, or abundances. In almost all regards, the initial surveys of the Pacific RAMP were exploratory assessments with the purpose of shaping this monitoring program. Perhaps, the logistical and financial challenges presented by the vastness and remoteness of the Pacific Islands Region, more than anything else, structured the initial scope of this program and continue to inform its evolution.

The primary role of an ecosystem-based monitoring program is to provide characterization of natural variability in environments and biological communities that in turn enables detection and understanding of anthropogenic impacts. In marine environments, specifically for dynamic coral reef ecosystems, this role presents an unusual challenge. Patterns of natural variability are quantified over broad temporal and spatial scales. Temporal scales include diurnal, seasonal, episodic (e.g., weather and storms), interannual (e.g., El Niño Southern Oscillation), decadal (e.g., Pacific Decadal Oscillation), and longer-term climate changes. Spatially, reef ecosystems vary over scales ranging from meters to thousands of kilometers. Ecological zones, such as intertidal, lagoonal, or barrier reef, and habitat types, such as reef slope, forereef, reef crest, backreef, and patch reefs, often vary as a function of prevailing or episodic oceanographic conditions (waves and currents, water quality, terrestrial inputs, etc.).

To document climate frequency oscillations, Pacific RAMP surveys have been conducted every 2 years and are now undertaken every 3 years. With the exception of oceanographic and bioacoustic moorings, which collect data nearly continuously, the Pacific RAMP cannot detect high-frequency ecological fluctuations. The triennial Pacific RAMP surveys are designed to examine ecological variability (multiyear to multidecadal) over longer terms, taking snapshots of an ecosystem at the time that surveys are conducted there. As such, many years worth of these so-called “snapshots” are needed before rigorous discussion of long-term changes become possible.

Operational and dive safety protocols limit the large majority of the biological observations to daylight hours in areas experiencing “workable” weather, sea, and current conditions. Although some Pacific RAMP survey methodologies, such as towed-diver surveys, provide a safe working environment even in harsh conditions, all survey types have safety limits. Because of these operational limitations, it is probable that many species remain spatially or behaviorally isolated from our surveys. For example, nocturnal species of fishes and invertebrates or species found preferentially in high wave energy environments cannot be effectively monitored using the existing sampling protocols.

Methodological improvements have been made over time among different Pacific RAMP cruises, introducing a degree of data variability. Such changes are necessary and common during developmental stages of long-term monitoring programs and reflect the relative infancy of the Pacific RAMP. For more information about the methodologies of the Pacific RAMP surveys and other data collection efforts conducted around the Mariana Archipelago, see Chapter 2: “Methods and Operational Background.”

Rapid Ecological Assessment (REA) and towed-diver surveys are the 2 general methodologies used to assess biological communities around each of the islands and reefs surveyed around the Mariana Archipelago during Pacific RAMP cruises. However, the spatial repeatability of these methods to date is still under consideration by CRED. The biennial surveys discussed in this report, therefore, have not explicitly surveyed precisely the same reef locations but instead reflect similar reef habitats and generally targeted depth strata (for further discussion of the depth and spatial limitations of survey methodologies, see Chapter 2: “Methods and Operational Background”). Changes in survey locations could have resulted in a high degree of variability among biennial data sets, especially considering the inherent spatial heterogeneity often observed in coral reef communities. Discussion of variability is incorporated within the context of the REA and towed-diver data analyses presented in this report.

For research that relies on consistent observer objectivity and training, reducing errors and biases are obvious yet difficult challenges. Ideally, observer bias could be largely eliminated with consistent research protocols and proper training and if repeated field observations are completed in the same areas by the same scientific observers over subsequent Pacific RAMP deployments. In reality, continuity among scientific personnel and reciprocity divers from multiple institutions is hard to achieve. Still, CRED is committed to improving consistency in field methodologies and onsite data collection and to implementing comprehensive, evolving training protocols (such as cruise-calibration dives) in an effort to account for and limit interobserver variability.

In addition to refining protocols and limiting interobserver variability, some protocols have been expanded or added to Pacific RAMP surveys in response to changing management priorities and an improved understanding of factors that affect coral reef ecosystems. Regular coral disease observations were added to the Pacific RAMP coral surveys beginning in

2006. Water sampling to determine carbonate chemistry was added in 2006 to better study the nature of chemical changes, such as ocean acidification, that are occurring on reefs. Chlorophyll-*a* and nutrient analysis from water sampling was added in 2004 and 2005, respectively, to measure the effects of sedimentation, runoff, and other factors influencing reefs. To improve the statistical validity of Pacific RAMP fisheries data and to meet new mandates in the *Magnuson-Stevens Reauthorization Act of 2006* to determine annual catch limits, CRED in 2008 incorporated a random stratified design for Pacific RAMP fish surveys using a stationary-point-count method, expanded the survey domain to encompass all hard-bottom habitat at depths of 0–30 m, and began steadily increasing the number of fish surveys conducted per Pacific RAMP cruise. While these changes are necessary to support improved stock assessments, there will be inherent effects on temporal comparisons. As part of the decade-long, international Census of Marine Life and its Census of Coral Reef Ecosystems project, the use of autonomous reef monitoring structures (ARMS) has been expanded to establish a global baseline of spatial patterns and initiate long-term monitoring of temporal changes in coral reef biodiversity. Development of techniques for processing the cryptic invertebrates that are collected with ARMS is ongoing. To form a baseline of accretion rates by crustose coralline red algae and hard corals, installations of calcification acidification units (CAUs) began in 2010, and data from CAUs will enable comparisons of net calcification rates between islands and archipelagos throughout the U.S. Pacific islands and help determine possible consequences of increased ocean acidity and lowered aragonite saturation states.

The CRCP and its predecessor, the Office of Habitat Conservation of the National Marine Fisheries Service, since 2001 have provided the significant majority of the financial support for CRED and the Pacific RAMP. In addition to program management and administrative support, this funding provides for the staffing of research cruises, the purchase of equipment and instrumentation, the completion of data analyses and management, and the production of publications associated with processed data. The availability of funds drives CRED's capacity, directly influencing the level of staffing for each of its research disciplines. Staff members are often at sea for 2–5 months per year, and this time away impacts the speed of data processing and dissemination. As a result, CRED is highly dependent upon local partners for supplementing staff support of research cruises. This involvement of local partners on research cruises brings local knowledge of coral reef resources to Pacific RAMP efforts but possibly negatively affects data consistency.

Large-scale data organization, quality control, and database structure are high priorities for the CRED scientific team. Proper data management and data flow practices are vital for streamlining and organizing the huge data sets that result from CRED's research in the Pacific. Significant progress has been made, as evidenced by this Coral Reef Ecosystem Monitoring Report for the Mariana Archipelago, and funding specifically for data management and infrastructure became available in FY 2007, but the implementation of data management protocols remains a work in progress.

While keeping in mind these constraints, CRED strives to increase efficiencies and improve all aspects of its scientific program. This report represents an installment of the ongoing effort of CRED to bring resource managers and interested stakeholders the best available, ecosystem-based data to help them make informed decisions about the sustainable use and conservation of their resources.

1.5 Structure of this Monitoring Report

Designed to present large-scale spatial and temporal snapshots of the coral reef resources in the Mariana Archipelago, this report is based on data collected during CRED-led MARAMP cruises in 2003, 2005, and 2007. Methodological descriptions and resulting analyses of habitat, oceanographic, and biological data sets are presented within discipline-specific categories. Under habitat mapping and characterization, for example, this report describes multibeam bathymetry and acoustic backscatter and optical validation based on TOAD and towed-diver benthic assessments. The category of oceanographic and water-quality monitoring includes spatial hydrographic surveys and time-series observations from moored instruments. Sections on biological community monitoring cover corals, algae, coral and coralline algal disease, other macroinvertebrates, and reef fishes.

To the extent possible, available socioeconomic data and information about human activities—including history, demographics, land use and cover, economic statistics, and environmental issues—have been incorporated into this report, along with coverage of geography and geology. A summary of this material for the Mariana Archipelago is provided in this "Introduction" chapter, and socioeconomic data pertinent to a particular island are included in the "Geopolitical Introduction" section of the chapter for that island. In Chapter 3 "Archipelagic Comparisons," socioeconomic data, on topics such as population and environmental stressors, are compared among the islands of the Mariana Archipelago to better understand how these factors interact and influence surrounding coral reef ecosystems.

Each chapter provides comprehensive, interdisciplinary data analyses for each island or bank. Habitat mapping and characterization data for each island or bank are presented as multiyear composite analyses across all survey years. Oceanographic and biological monitoring data are presented mostly in a cruise-specific sequence so that temporal and spatial patterns of abundance and distribution can be explored. The main body of this report includes data collected for each island, spatial and temporal analyses of this data, and an integrated, ecosystem-based assessment of findings. The final chapter of this report examines archipelagic comparisons of integrated ecosystem observations to evaluate similarities and differences among the islands of the Mariana Archipelago on a regional scale, including the large-scale processes that influence the coral reef ecosystems around them. Using a linear additive model, 2 sets of benthic, fish, and coral reef condition indices compare (1) all islands of the Mariana Archipelago and (2) only the 4 populated, southern islands. The first set of these indices appears in Chapter 3: "Archipelagic Comparisons," and versions of the second set appear in the "Ecosystem Integration" sections of Chapters 4, 5, 7, and 8 for the islands of Guam, Rota, Tinian, and Saipan.

This document provides scientific data to assist local, territorial, and federal stakeholders with the challenges they face in the long-term management and conservation of their coral reef ecosystem resources. The information in this report serves 3 main purposes:

- Provide overall spatial and taxonomic snapshots of the coral reef resources around each of the islands in the Mariana Archipelago during each survey period
- Form foundation of knowledge about ecosystem conditions in the Mariana Archipelago for ongoing monitoring of temporal changes
- Deliver tool for stakeholders and resource managers for investigating marine areas of interest and formulating evolving management questions about how to best manage marine resources

At the conclusion of each MARAMP cruise, data collected by CRED scientists and local partners have been presented to the resource management agencies in the CNMI and Guam in the form of cruise reports. These cruise reports contain summary information—including area and types of operations; itinerary and daily activity record; cruise statistics; missions; list of scientific personnel; and types of data collected. Appendices to these cruise reports have provided descriptions of the methods used for data collection for each discipline as well as summaries of key data and the types and numbers of surveys and other activities performed by island. This Monitoring Report for the Mariana Archipelago, then, is intended to provide in-depth analyses that complement the summary data provided in these cruise reports.